Research advance in wood composites in China

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Abstract Wood composites can generally be classified in three parts: laminated composites, mixed composites and penetrated composites. Every part has its own characteristic and can be further divided. This paper introduces the history and the state of development of wood composites in China. The research about glue-laminated timber is rare and the industry hardly comes to being. A great of achievements have been obtained in mixed composites and it is well industrialized. Many studies on scrimber have been done and the Chinese researchers are looking for a feasible way to develop the scrimber industry in China. Chinese researchers also spent so much energy in studying wood plastic composites (WPC), but it has not been industrialized due to the high cost.

Keywords: Wood composites, Research advance, China

In the 21st century, the wood supply in China will continue to be less than the demand, so China will need to use wood as effectively as possible. The use of wood composites is a very efficient way to save wood. China lacks sufficient forests to meet its demand for wood, especially in fine quality woods. Because of China's population and fiber demand, efficient use of wood is more important to China than that to some other countries. However, China was neither convinced of this and nor did it pay attention to the study of wood composites before the 1970's. Facing the wood crisis China found it necessary to emphasize the study of wood composites and consequently has made great progress in the past years.

Wood composites are made of wood (or non-wood fiber materials) and other materials. Some of them are lower cost materials than solid wood, some are products that can utilize recycled materials and have the products themselves be recyclable, and others exhibit specific properties that are superior compared to either of the component materials alone (e.g. increased strength-to-weight ratio, improved abrasion resistance, etc.) (John 1995). Wood composites can generally be classified in three parts: laminated composites, mixed composites and penetrated composites. Every kind of wood composites has its own characteristic and still can be divided into many parts (Li 1995).

Laminated composites

Laminated composites are kinds of certain size, shape materials made of small logs, lops and tops. The manufacture process includes cutting small logs and others into flakes, then laminating, gluing and compressing them. LVL (laminated veneer lumber), PSL (parallel strand lumber), triboard, glued laminated timber (i.e. assembled body of wood) and scrimber are new products made of laminated composites in this century. This paper emphasizes the latter two.

Glue-laminated timber was invented in Germany at the beginning of this century and then used in construction. The first glue-laminated timber was a straight beam composed of several laminations bonded with adhesive. The technique was developed in Europe at first. The Americans, Japanese and others studied it one after the other. In 1995, there were approximately 30 manufacturers of structural glue-laminated timber throughout the United States. China had known little about it until the 1970's. Wang Songyong did some studies on residual strain on an assembled body of wood (Wang 1972) and the flexural properties of laminated beams (Wang 1978) in Taiwan. The balks of glue-laminated timber used in Asia Sport Village of Beijing were made by China itself (Li 1993). A resorcinol-phenol formaldehyde resin was developed for bonding laminated wooden beams which have a large cross-section and used under a sever condition. This kind of resin can be cured at room temperature. In order to determine its performance, some tests on internal bond and weathering were carried out and the properties of the resin were discussed. The results indicated that the performance of the resin could meet designed requirements (Luo *et al.* 1990). Glue-laminated timber can replace steel to make into arch. Glue-laminated arches proved less costly than steel and more decorative. So it should be used in construction more and more. However, China is short of wood. The government advocates that steel and plastic replace wood. So the research about glue-laminated timber is rare and the industry hardly comes to being.

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The study of scrimber started in Australia in 1973, and many other countries followed its step. Scrimber is made of small wood, lumber thinned, lop and top, which are tinpot, by grinding and rubbing, drying, spreading, sizing and compressing. The fiber is loose, but is not broken, and the direction of fiber is not changed. The basic characteristics of wood are kept, and the product almost has the same strength as beam. So the product has excellent performance. In 1976, the Institute of Wood Industry, Chinese Academy of Forestry and Wood Factory of Jiangxi cooperated in exploring the development of scrimber and manufactured the first product. The MOE of these products were 4.8~10 GPa. Hua Yukun and his colleagues visited Australia in 1989. They had a detailed discussion in detail with the inventor and his staffs, and looked around the scrimber labs. Later, Prof. Zhu Guoxi and Ma Yan of Northeast Forestry University (NEFU) went to Australia for seeing about scrimber. They did a lot work in the theory of its manufacture, technology, and facilities. The Institute of Wood Industry, Chinese Academy of Forestry expanded the study to bamboo and took the study to a new field. Many scholars had done many studies and written many papers on scrimber, such as Pan Shifeng and Wang Ximing of Inner-Mongolia Forestry College, and Li Jian and Ma Yan of NEFU. They are looking for a feasible way to develop the scrimber industry in China (Jin *et al.* 1998).

Mixed composites

Wood fibers, particles, flakes or lumber can be mixed with cement, gypsum, slag from furnace, plastic and other materials, and molded various boards. By this measure the cost of board can be decreased or the board can be endowed with some new properties. All these products belong to the big family of boards known as mixed composites. Some of the products can be used in a variety of structural applications such as cement-bonded board and gypsum-bonded board. These composites have a unique advantage over some conventional building materials because they combine the characteristics of both the wood and another matrix. Some of these composites are moisture resistant and can withstand the rigors of outdoor applications, and almost all are either fireproof or highly fire-resistant, and are very resistant to attack by decay fungi.

Cement-bonded board has been manufactured in Europe since the 1930's and used in building construction for half a century, but have not been able to break into the panel market in the fiber-rich United States. However, over the last decade, the roofing products industry has developed a niche-market for cement board products. China succeeded in studying it in the 1970's and it has been developed quickly and launched into manufacture in the 1980's. Cement-bonded board is one of the new-type materials. To develop cement-bonded board conforms to China's industry policies because of environment protection. However, the multiformity of their products is insufficient. Design and color are too monotony to be used at large. Now they take aim at using it as inner-clapboard in constructions.

By the end of the 1980's, the study of gypsum-bonded board had bloomed in China. Many projects had been carried into execution. For example, "In connection with a bilateral project sponsored by BMFT 'utilization of lignocellulose for the manufacture of board-type materials' between the Fraunhofer-Institute for Wood Research, Germany (FRG) and the Chinese Research Institute for Wood Industry (CRIWI), FRG took over amongst others the task to project a plant for the manufacture of gypsum-bonded particleboard according to the semi-dry process." (Mehlhorn *et al.* 1990) They studied the physical characteristics of gypsum-bonded particleboard, such as its water-resistant property. Li Xiaoming and Chen Shiying at CRIWI studied the influence of cement appended on the water-resistant property of gypsum-bonded. By their experiments, they got the conclusions that cement bates the solidification of gypsum, the water extractives also bate the hardening of gypsum, and the moderate additive of cement is helpful to the water-resistant property of gypsum-bonded (Li *et al*, 1989). At the same time, Zhang Yi (1989) was working on the study of the compatibility of some wood species to the manufacture of gypsum-bonded particleboard and the influence of wood extractives on hardening and properties of gypsum plaster and gypsum-bonded particleboard. He got some results: (i) the strength of gypsum-bonded particleboard becomes evidently higher with the increase of density, (ii) raising wood-gypsum ratio can result in increase of MOR etc, but no influence on MOE and internal bonding strength, (iii) water-gypsum ratio plays no role on properties of board in the range of 0.30-0.40, (iv) the three factors mentioned above have no interaction.

The influence of wood extractives on the hydration and the bending strength of gypsum plaster and gypsum-bonded particleboard was examined under the existence of commercial retarder RETARDAN P. Wood extractives can retard the hardening of gypsum plaster and gypsum particle-board, and the bonding strength is also declined. Wood species and the quality of gypsum also play important roles for the degree of influence. Wood extractives can reinforce the retarding effect of RETAREAN P. Meantime the setting time of gypsum particleboard can be predicted by that of gypsum plaster under interaction of both.

The bending strength of gypsum particleboard depends on the wood species, but does not evidently on the addition of retarder. The compatibility of *Populus davidiana, Betula platyphylla, Quercus mongolica and Picea abies* as well as the mixture of the former three species with the manufacture of gypsum-bonded particleboard was studied. At the same technical parameters, the gypsum-bonded particleboard made of the lower density species with higher MOR, i.e. spruce board is the strongest, then poplar and birch, the board made of oak is the weakest. Spruce and poplar are suitable species for the manufacture of gypsum-bonded particleboard, but the qualified birch and oak boards were not obtained even through the change of wood-gypsum ratio and wood particle volume, water extraction of wood particle. Mixture of various wood species will not only offset the hydration time, but also make the quality of gypsum-bonded particleboard unstable, which should be avoided in practice (Zhang 1990). Xu Wei studied the possibility of making gypsum-bonded board with cotton stalk instead of wood particle using the semi-dry method. The results showed that although the cold water extractives of the cotton stalk retards the setting of gypsum, the setting characteristic of gypsum is changeable and can also be controlled by adding certain chemical accelerator or retarder. The influences of some production parameters were also investigated on the properties of the board. The main production parameters would be suggested that density of the board be less than 1.2 g/cm^3, the ratio of cotton stalk and gypsum be less than 0.25 (by weight), and the ratio of water and gypsum be 0.40 (by weight) (Xu 1988). Hua Yukun and his staffs at Nanjing Forestry University studied the main characteristic of mineral slag particleboard. The mineral slag particleboard they obtained under optimal condition had the physical performance as follow: the density was 1220 Kg/m^3, MOR was 17.3 MPa, MOE was 4270 MPa, IB was 0.48 MPa, and it could be used under humid condition (Hua *et al.* 1989). Mr. Hua finished the study of the technology in April, 1990, and the technique succeeded in appraising in 1991.

Most of the studies about mixed composites were done by CRIWI. At the same time, the study of other mixed composites made large progress in NEFU. The middle-scale experiment board made of reed or hards which was presided over by Li Kaifu got through experts' appraisal (Li. 1994). China has a big agriculture so scientists wanted to make use of surplus corn fiber to alleviate the crisis of wood. Also some researchers looked for the way that the composites of bamboo or ramie fiber instead of wood (Li. *et al.* 1994a, 1994b, Zeng. *et al.* 1995). Recently, biomaterials are paid attention to for sake of the environment crisis, but this is not very true in China. Few papers about them can be found besides the two papers by Zeng Qiyun and his colleagues. Asia Pacific Timber Industries invented a new artificial board using soybean, but the Chinese research was not published.

Penetrated composites

Penetrated composites are made by some liquid penetrating into wood cell and then polymerizing within the wood. They can be considered as wood modified. The liquid must not be sticky and the wood have better to be a hardwood of low density in order that the liquid penetrates into its cells easily. The liquid may be an inorganic solution, or melted metal, or organic material including low molecular weight resin, monomer such as MMA (Methyl-methacrylate), and some reagents which can acylate, esterify or etherealize wood. People want to keep the merits and ameliorate the shortcomings of wood by such measures. The biggest disadvantage of wood is that it swells in moist environment and shrinks in dry. Scientists had found many measures and many agents to improve wood dimensional stability. Many of the agents can react in or with the cell wall of the wood in order that this disadvantage can be released. You Jixue and his cooperators treated *Populus* wood with urea formaldehyde concentrate to improve wood properties. The modified *Populus wood* showed the decay resistance, dimensional stability and mechanical properties much better than the control (You *et al.* 1989). Many of treatments with inorganic solutions can make the wood flame-resistant or fungi-resistant, but the treated wood often absorbs moisture more easily. Many of the organic monomer are helpful in strengthen the wood. Monomer can polymerize in the cell lumen of wood so that the treated wood becomes stiff and wearable. The monomer must get enough energy from atomic radiation to polymerize or a certain initiator makes the monomer polymerized under heated. The wood treated with organic monomer is called WPC (Wood Plastic Composites). It was invented in 1961 and is treated as one of the ten most momentous American achievements in science by America.

In China, the work on WPC also started in 1960s. Shanghai Institute of Atomic Energy took the lead in study of WPC created by atomic radiation in 1977. The research group studying WPC made of poplar came into existing at CRIWI and they got a good recipe. Wood plastic composites (WPC) made from Chinese white poplar (*Populus tomentosa*) and Canadensis were studied by them. They chose styrene containing a small amount of cis-polybutadiene, divinyl benzene, benzoyl peroxide, tert-butyl perbenzoate and hydroquinone as an impregnating liquid for preparing WPC. This impregnating liquid with rather

long pot life could be polymerized in higher conversion. The properties of hardness, abrasive resistance, impact strength, static bending strength and dimensional stability of WPC prepared with this impregnating liquid were improved significantly, and increased with increasing the polymer content in WPC. The temperatures at centers of wood samples against polymerization temperatures, amount of initiators, dimensions of wood samples, antioxidants, U. V. stabilizer and time of polymerization were determined. From these, some better control of this kind of polymerization was proposed. The influence on the properties of WPC prepared by the addition of an oil soluble surfactant -- O Π-10, or a surface treating agent--toluene diisocyanate in this impregnating liquid was studied. It was found by scanning electron microscope, that the polymer was better distributed in WPC prepared by the impregnating liquid containing a small amount of O Π-10 than that without it, but the bonding properties between polymer and wood cells were still not tight enough (Research group of poplar WPC 1980). Ge Mingyu and his colleagues studied making WPC by heat at NEFU. AIBN was chosen as initiator and the result of the experiments showed that AIBN was harmful to the wood hardness because there were some blebs in the polymer due to AIBN decomposed under heated (Ge *et al.* 1983). Although Chinese researchers have spent so much energy in studying WPC, it can not yet be industrialized. The basic reason is that the cost is too high and the product is too expensive to use. This is a problem not only in China but also in other developing countries.

All in all, through research and development, some wood composites are beginning to take the place of solid wood such as laminated lumber and mixed lumber, and some treated wood can be unique or more durable such as WPC, fire-resistant wood and fungi-resistant wood. Furthermore, the materials of wood composite are bad quality wood, that is, lops and tops, and surplusage, so it will still be the material focused in 21st century. Therefore the study of wood composite is important to China. This study started lately in China, but it has done a lot in the past years. China is working on accelerating the development of the study and catching up with the rest of the world.

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